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Rethinking Tornado Design

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RETHINKING TORNADO DESIGN

A Thesis Presented

by

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Approved as to style and content by:

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Kathleen Lugosch, Chair

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William T. Oedel
Chair, Department of Art, Architecture, and Art History

DEDICATION

I dedicate this to my family and friends that supported me through school.

ACKNOWLEDGMENTS

I would like to thank my professors, David Dillon, who encouraged me to pick a topic that is close to the heart and helping me get started in the thesis process; Kathleen Lugosch, who kept me on the right path and making me stick to a schedule.

I would also like to thank my classmates for two years of fun studio time and making this place seem more like home.

ABSTRACT

RETHINKING TORNADO DESIGN

MAY 2011

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Directed by: Professor Kathleen Lugosch

Oklahoma is in the middle of Tornado Alley, a name resulting from the large number of tornadoes that hit the region yearly. These storms are costly to life and property.

The housing in Oklahoma is currently not well enough engineered to withstand tornados. This thesis proposes a three stage response combining construction technology and the use of landscape to better protect the homes and residents of Oklahoma.

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HISTORY

Introduction

I come from Oklahoma, which is in the middle of Tornado Alley, a portion of the United States that is frequently hit by deadly tornadoes. Oklahoma gets more tornadoes a year then any other state besides Texas and that is only because Texas is significantly larger then Oklahoma. The reason we in Oklahoma are hit by so many tornadoes is our location in the United States, warm humid air from the Gulf of Mexico and cool air from the upper atmosphere mix over the skies of Oklahoma, and these conditions can make tornado producing storms. Tornado season for us is usually the spring and summer months but more and more tornadoes have been known to occur year round.

My research is expired by the city of Moore Oklahoma; Moore is an offshoot of the Oklahoma City Metropolitan area. Moore was all most wiped off the map due to an EF5 tornado on May 3rd 1999. This was a large mile wide tornado that had winds of 318 miles per hour, the highest wind speed ever recorded in history. Seeing this destruction of a neighborhood, thoughts go through my head on there must be something that can be done.

What can be done to better protect the people of Oklahoma? I will look at the broader scale of housing and what can I do to redesign the house to better protect the people. While looking into what can be done for the housing I will take a look at what changes can be made to the surrounding environment to provide better protection for housing. Through my research I will look into how to redesign a house and the landscape in which it is built to make a safer environment against the extreme weather of Oklahoma. To accomplish these goals I will look into meteorology and what causes the weather where it is most likely to hit and what precautions can be taken. Other research that I will investigate is wind engineering, building materials and construction types. With this information I will address the redesign of the Oklahoma house to better protect against extreme weather and help prevent this large scale destruction of housing in Oklahoma.

Weather

Tornadoes can occur anywhere in the United States but mostly occur in a portion of the Midwest called Tornado Alley. A tornado forms when winds change in direction and speed and create a horizontal spinning effect within a supercell thunderstorm. These supercell storms are known for the presence of a mesocyclone, which is a deep continuously rotating updraft. This will all occur when the weather conditions are right, when warm, humid air near the ground and southern winds combines with colder winds from the west and southwest that are found in the upper atmosphere, this will cause a funnel cloud to form and work its way to the ground and a tornado is born[1].

Tornadoes often occur in late afternoon when thunderstorms are more prevalent and in the spring and summer seasons. However tornadoes can happen at any time of the day and year, there is no time you are safe from a tornado.

[1] (NOAA 1992)

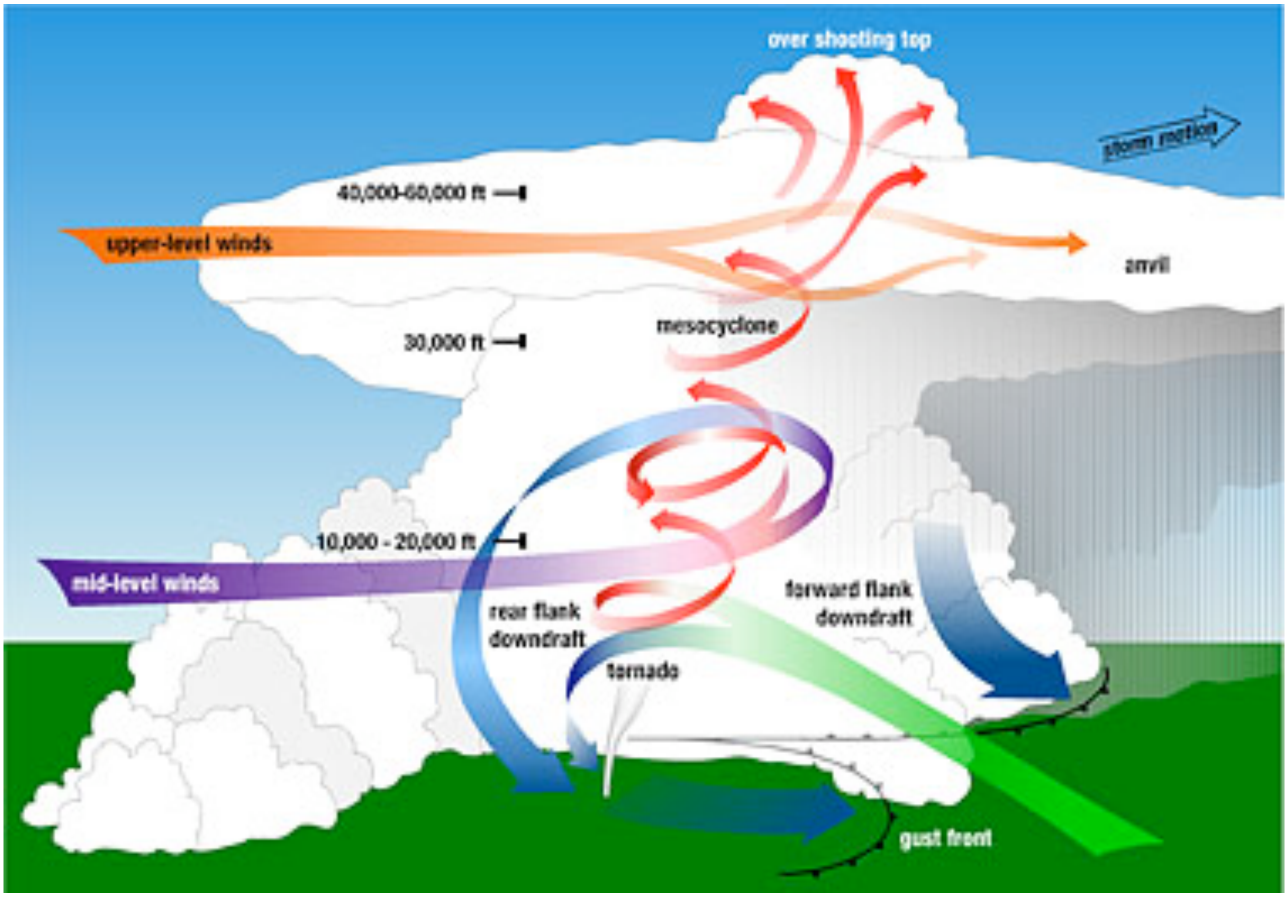

Figure 1: Tornado Development
Taken from NOAA

The Hook Echo is the classic marker that a supercell thunderstorm has the right condition to produce a tornado. The hook echo is produced by rain, hail or debris being wrapped around the mid-level mesocyclone. The mesocyclone has a counter clockwise winds moving north to west to south to east and around, which result in the hook echo having a cyclonically shaped hook. This hook is found in the tailing end of the storm between the main storms updraft and the storms rear flank downdraft (RFD) where these changing wind directions can cause a tornado. Most tornadoes are produced with in a hook echo. When a hook echo is detected in a storm the meteorologists have cause to announce a tornado warning[2].

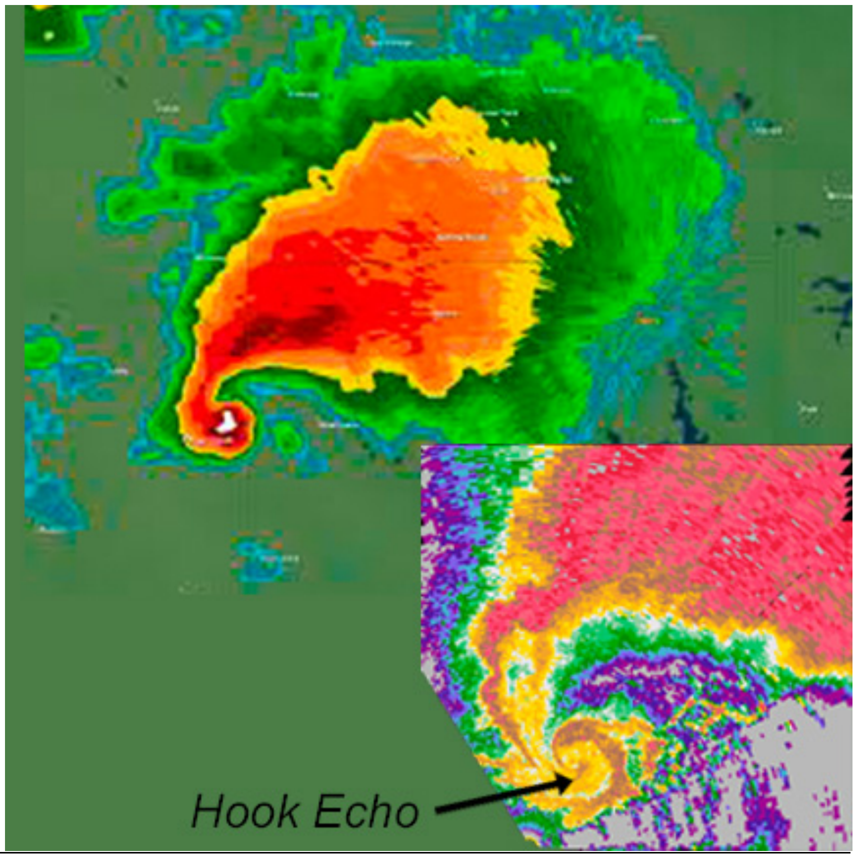

Figure 2: Hook Echo
Made by Author

Tornado Classification

The Enhanced Fujita Scale, a scale that classifies a tornado from EF0 to EF5 or from weak to strong. The EF0 tornado has winds clocked around 65-85 mph capable of peeling surfaces of roofs and breaking branches off trees. The EF1 tornado has winds

[2] (Hook Echo 2010)

around 86-110 mph and can overturn and severely damage mobile homes. The EF2 tornadoes winds reach to 111-135 mph and roofs can tear off houses, shift houses off their foundation, completely destroyed mobile homes, uprooted large trees, generate light object missiles and lift cars off the ground. The EF3 tornado generates winds from 136-165 EF3 winds will destroy entire stories of well constructed homes, severely damage large structures, overturn trains, debark trees, lift heavy cars off the ground and throw cars and structures with weak foundations for some distance. The EF4 tornado has winds from 166-200 mph. With these winds well-constructed houses and whole framed houses will be completely leveled, cars thrown and debris will become destructive missiles. The EF5 and the most deadly tornado has winds over 200 mph and has been clocked with winds in excess of 300 mph. Strong framed houses are leveled and foundation swept away. Automobile sized missiles fly through air. Steel reinforced concrete structures are severely damaged and high-rise buildings have significant structural deformation.[3] This size of tornado is a killer. To survive you must be underground or in a fortified tornado resistant structure.

The most intense winds of over 200 mph are found in 2% of all tornadoes but they cause 70 percent of all death and can last over an hour. Not to be over looked but 50% of tornadoes have peak wind speeds of 90 to 110 mph, which still can cause significant damage.[4] We cannot forecast tornadoes like meteorologists can forecast hurricanes, so this makes our warning system very short. The average warning time is approximately 13 minutes. Under these conditions being able to live in a tornado safe home can save your life

[3] (NOAA Fujita Scale)
[4] (ASCE 1999)

Destruction from F0 Tornado

Destruction from F1 Tornado

Destruction from F2 Tornado

Destruction from F3 Tornado

Destruction from F4 Tornado

Destruction from F5 Tornado

Figure 3: Fujita Scale Rating
Public Domain NOAA

Tornado Details

Tornadoes are unpredictable and very erratic in how they form, the paths they travel and their duration. As I cannot design for the wide-ranging erratic behavior of tornadoes, I am designing to address the most often occurrences.

In Oklahoma tornadoes mostly occur during tornado season; in the spring and summer. These tornadoes most commonly travel from the southwest in a northeast to east direction at a speed around 30 mph, but have been documented at a speed of 0 and up to 70 mph. When looking into travel paths of tornadoes I have looked into the research of Dr. Fujita and his studies of tornadoes for 70 years. The studies found that 58% of tornadoes come from the Southwest and 18% come from the West, this accounts for 76% of all the tornadoes that are seen in the United States.[5] This is a key point in tornado design because we know the direction in which large majorities of tornado producing storms are coming from and designs can be made for this situation. The path of destruction can range from 100 yards wide to a mile wide and a travel length of 15 miles. Tornadoes can last a matter of a few seconds to more then an hour but usually they do not exceed 10 minutes. Through his research Dr. Josh Wurman documented that the highest wind speeds are found at the base of the tornado and in the upper atmosphere of the super cell. This high wind speed at ground level will cause a debris cloud that circulates the debris outward and upward in a counter clockwise conical pattern. This spinning debris cloud is what does most of the damage to structures. [6]

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[5] (Fujita 1987)
[6] (Wurman 2004)

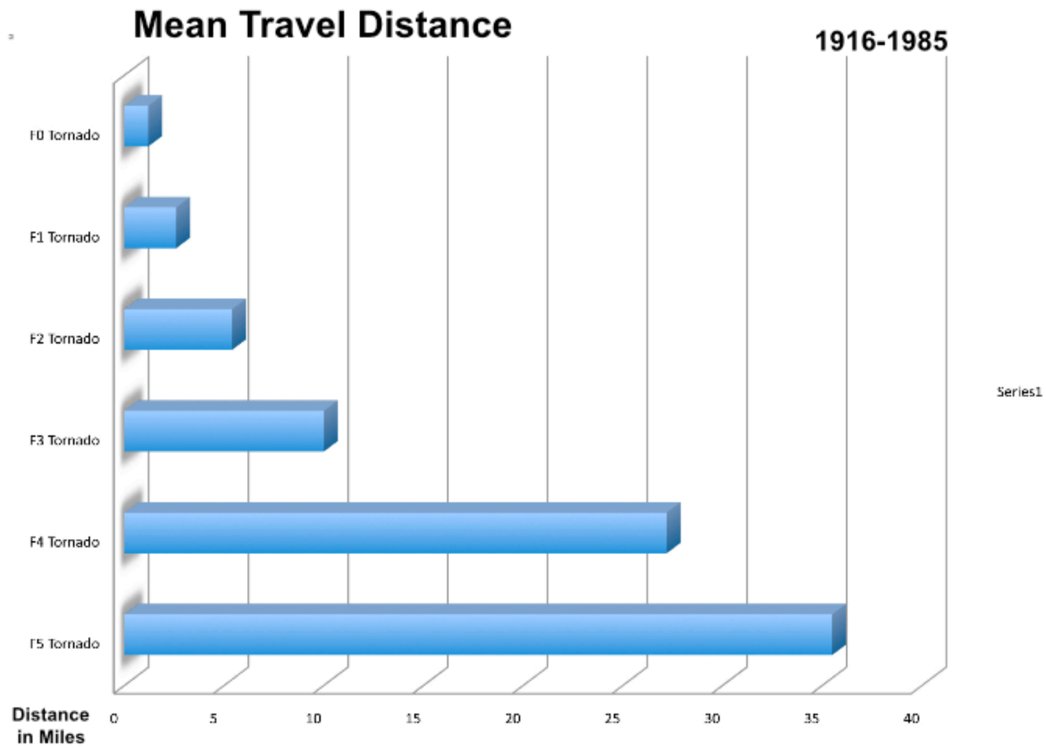

Figure 4: Mean Travel Distance
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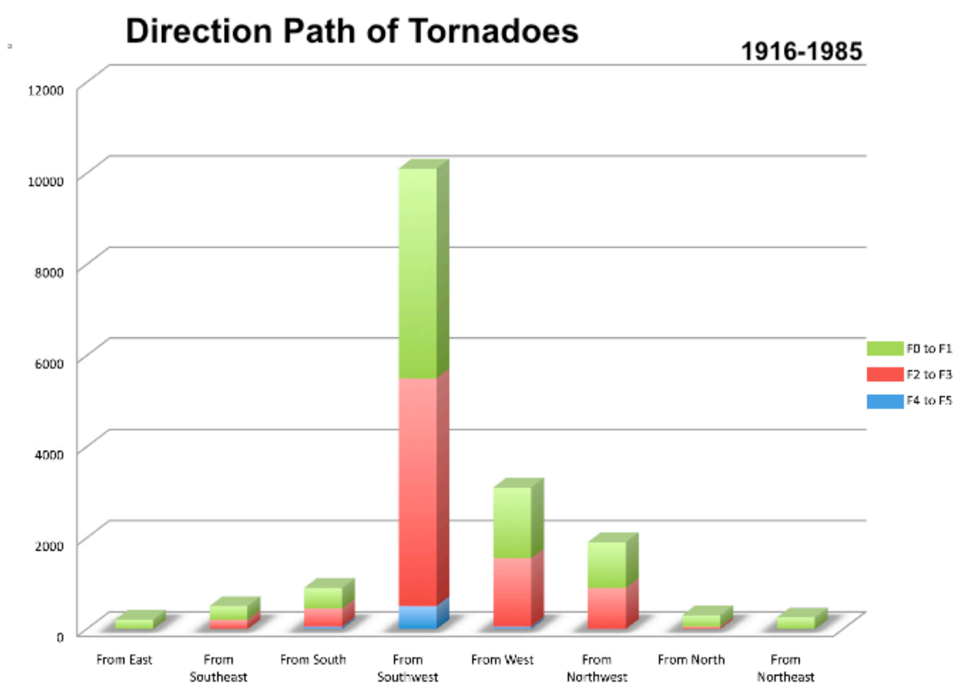

Figure 5: Direction Path of Tornadoes
Made by Author

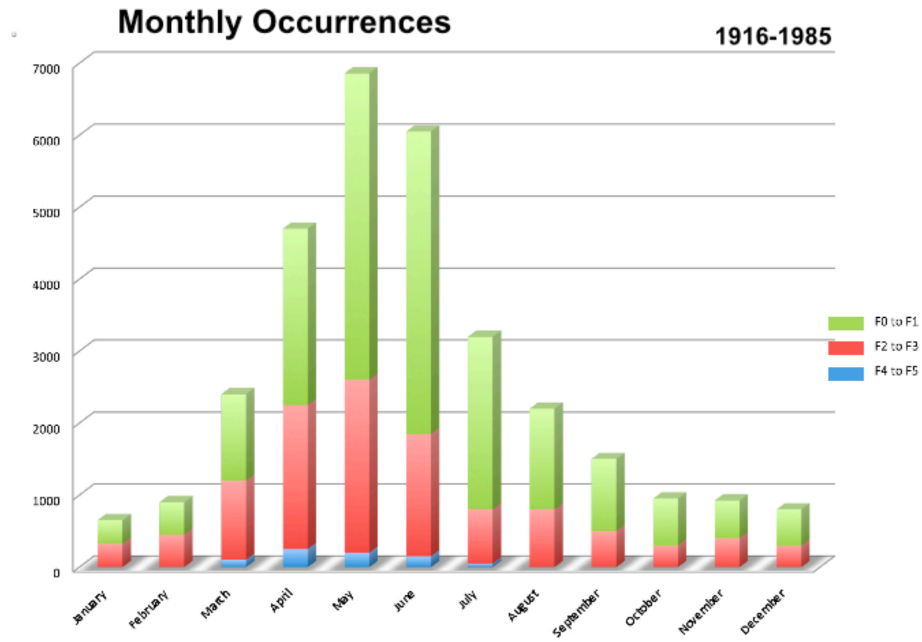

Figure 6: Monthly Occurrences
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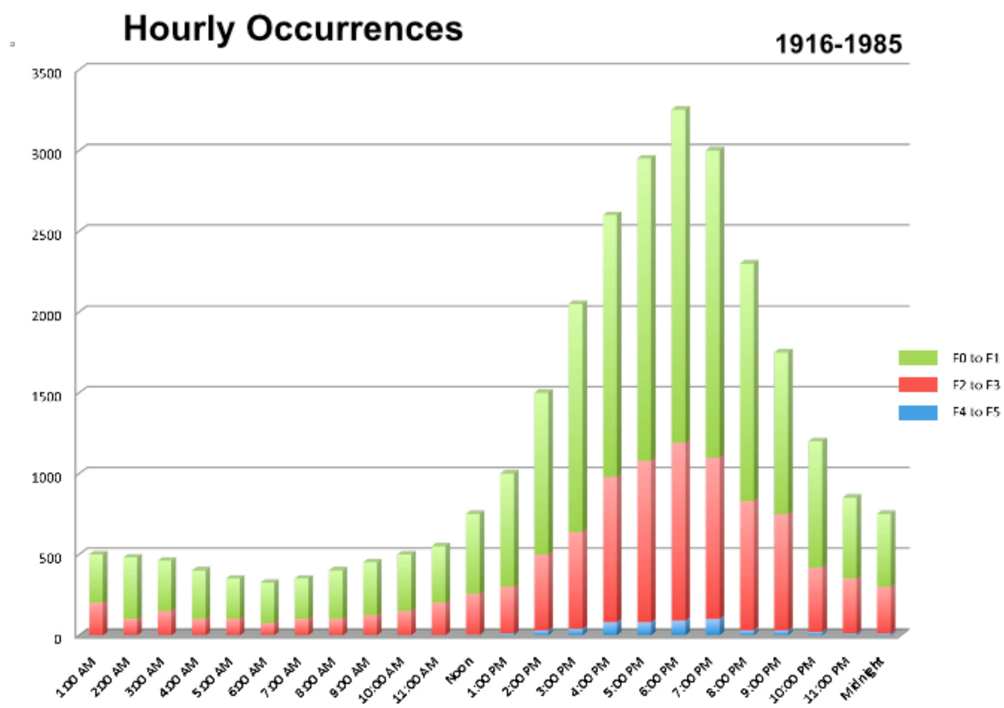

Figure 7: Hourly Occurrences
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Spencer Tornado

The Spencer tornado in 1998 was tracked from its beginning to its end. This storm started producing tornadoes around 8:00 pm through 8:45pm; this storm dropped a tornado on Spencer at 8:37pm. This storm caused the second deadliest tornado in South Dakota killing 13 people and causing 500 million dollars in damage. The damage path of this tornado was investigated in Spencer, North Dakota, at the center of the tornadoes damage. This tornado was a F4 classification traveling east. The structural damage extended 100m to 150m north of the center of the tornado and 200m to 250 south of the center. This was also confirmed in the F-scale ratings for damage, which along the north track of the tornado was F0 to F2 and along the south track was from F0 to F4. The velocity differential would result wind speeds nearly 30m/s higher on the south side of the tornado. There was a difference in F-scale rating of 1.5 to the north and south of the center; which is a significant difference. With a damage differential ranging from losing a few shingles off of your house to the total destruction of your home this shows in the case of the Spencer tornado that depending on what side of the tornado the house was on determined how much damage the house would receive. [7]

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[7] (Wurman 2004)

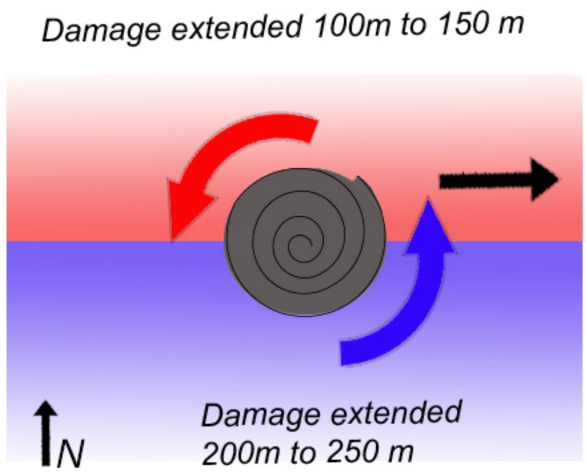

Figure 8: Spencer Tornado
Made by Author

Moore Oklahoma

Moore was founded during the land-run in 1889.[8] Moore is about 15 minutes south on I-35 from the downtown area of Oklahoma City. Moore as been damaged by tornadoes on October 4th 1998, May 3rd 1999 and May 8th 2003, where the may 3rd at least 76 tornadoes hit the ground killing more then 50 people, the Oklahoma city Metropolitan are was hit the hardest were 43 people died, 10,000 homes were destroyed or severely damaged and 0ver 1.1 billion dollars in damage.[9] One tornado ripped right through the heart of Moore Oklahoma and this tornado was an EF-5 on the enhanced

[8] (Moore Wikipedia)

Fujita Scale and was the strongest and most destructive tornado ever recorded in history. The winds speeds where clocked at 318 mile per hour and this tornado left a swatch of destruction a mile wide at time and seven mile long. Moore has a special place for me because I saw the destruction first hand and was a part of the volunteers to clean up this devastated area. It was total devastation for as far as the eye could see, houses leveled to the foundation, trees uprooted and blown away, and cars wrapped around the trees that were still there. Even when I thought there were some lucky people were their house was still standing, I asked them how lucky you must be and they gave me a tour of their home. The houses that did not get leveled were completely gutted and ravaged on the inside from the wind and flying debris. To this day I think to myself there as got to be something better out there to protect people form these storms.

There was so much destruction that day because of the buildings lack of protection; many of these structures were not designed to with stand the wind loads from even the weakest of the tornadoes that day. The largest contributors in the damage of a home are the wind load placed on the structure and the flying debris caused by this wind. The debris caused by a tornado breaches the buildings envelope by breaking the windows, doors and destruction of the roof covering. This breaching causes increase pressure on the walls and roof of the structure, which will cause the failure of the structure, which might of other wise survived the tornado. Most of the homes and buildings in Oklahoma are designed for gravity loads; the amount of reinforcement is sufficient for these loads but cannot handle the lateral loads cause by a tornado.

Historical Housing for Oklahoma

The first housing for settlers when they came to Oklahoma was the sod house or soddy. This is a house that is made from cut pieces of sod and stack on top of each other like bricks. Sod was used because that was the most abundant resource around, Oklahoma is located in the Sothern portion of the Great Plains and there are not that many trees around to use for construction.

Traditional Wood Framed Housing

The majority of people today are living in the traditional wood framed or stick framed house. Siding on the houses are made of three materials wood, vinyl or brick, brick is commonly used because of its affordability, it is priced similarly with wood or vinyl and it is very durable. The masonry on modern houses is a brick veneer and are not suitable for impact loads or lateral loads caused by the tornado and this is proven over and over from the collapsed walls caused by tornadoes in the passed. Texas Tech University has done test where they shoot a piece of dimensional lumber at a wall at 100 mph. They have shown that the wall structure, even with a brick veneer can't stop a 2x4 flying at 100 mph[10]. These houses have proven that they cannot with stand the extreme loads placed on the house during a tornado.

Tornado destruction

The three main causes of structural failure caused by a tornado are improper roof connections, debris penetration and improper foundation connections. The first cause is

[10] (Turner)

due to improper roof connections, the high winds from a tornado will blow the roof off of the walls. With out a roof to tie the walls together they loose strength and the wind can easily topple the structure. The second cause is debris penetration, the debris rips through the house undermining the structure and causes the house to fail and then that house collapses and becomes the debris, which will destroy the neighbor's house. The last main cause of housing collapse is improper foundation connection. Many house are held to there foundation by gravity or nails. With an improper foundation connection high winds can blow a house right off it's foundation. These homes are not built to withstand high wind loads and flying debris. This why people need to look into houses that are better equipped to handle these severe situation and can protect them from danger.

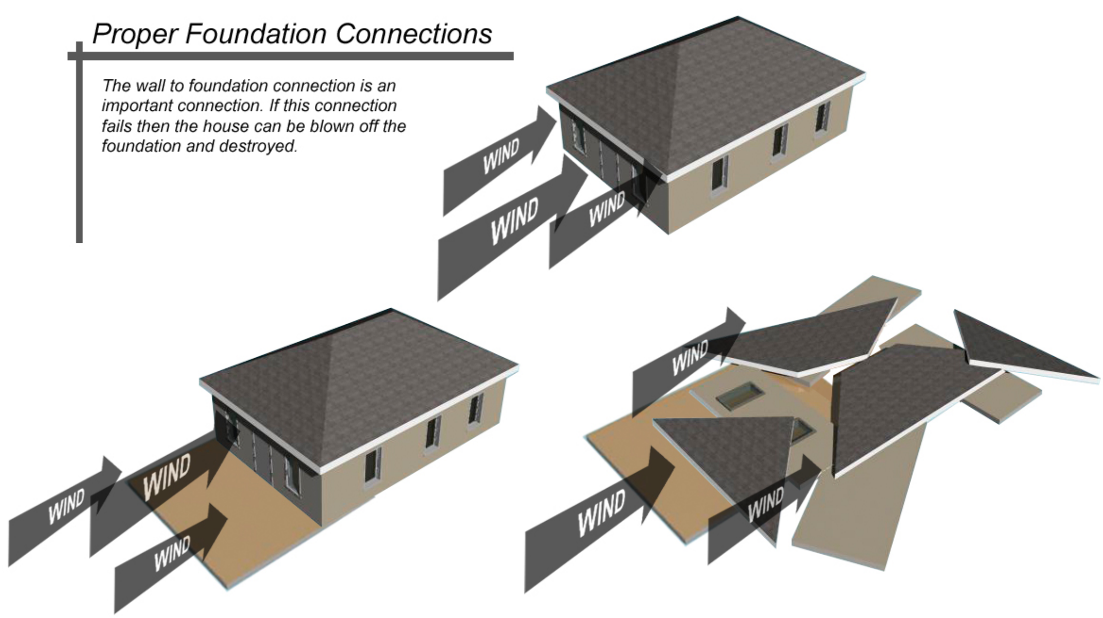

Figure 9: Proper Foundation Connections
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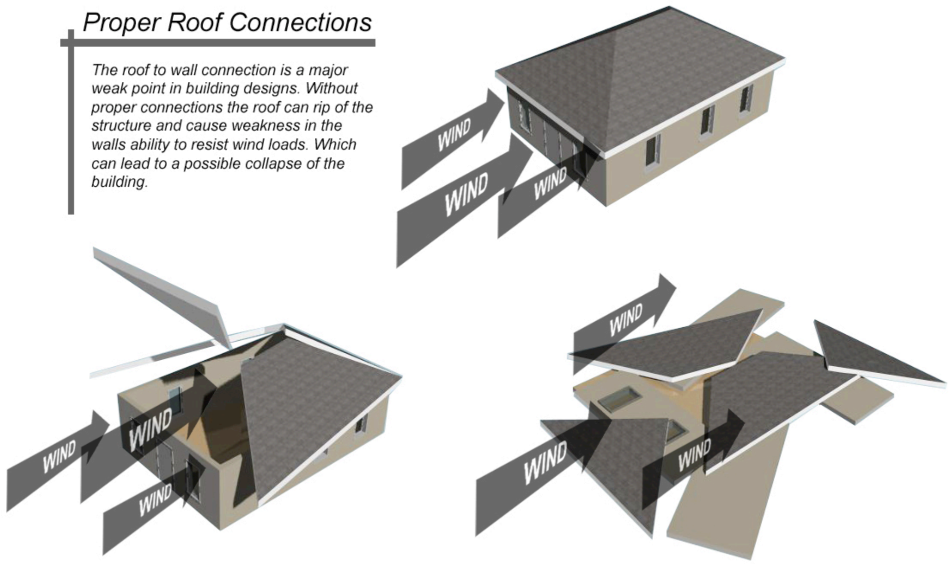

Figure 10: Proper Roof Connections
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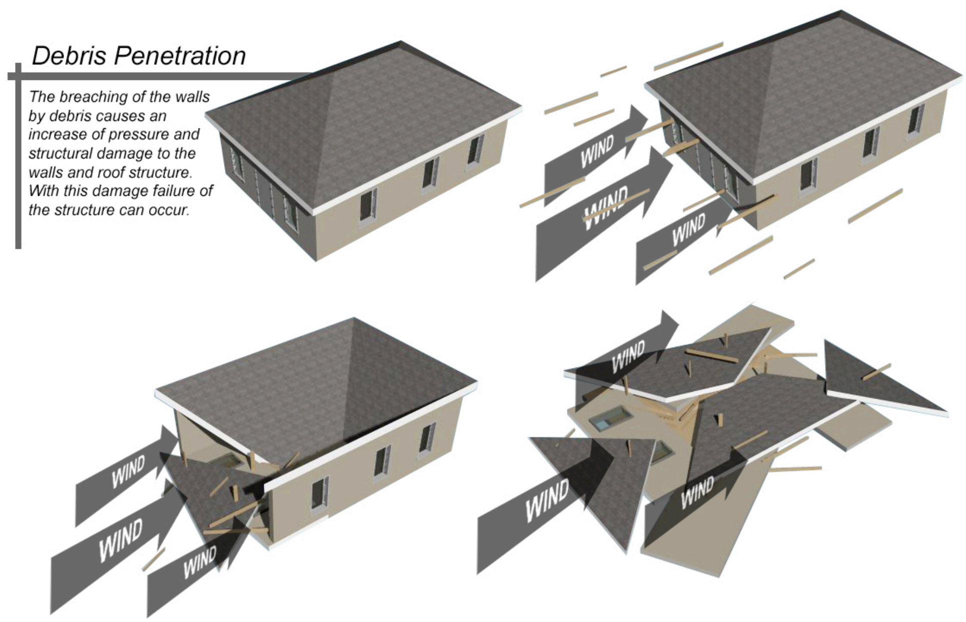

Figure 11: Debris Penetration
Made by Author

CHAPTER 2

WIND TESTING

Wind Breaks

Windbreaks have been used to protect crops from wind damage and the soil from erosion. In this research that I have done I am looking into different landscape elements and how they can be used to protect buildings and structures from the high winds caused by tornadoes. In this research I look at the use of vegetation, berms, hills and walls to block the wind. Wind flows around obstructions like water, you cannot block it just redirect it or slow it down. When water flows down a river the surface of the water is moving faster then the water near the riverbed. This is due to the contours and shape of the riverbed and from any obstructions that the water must flow around. I am looking to do something similar and arranging the landscaping and making obstacles to slow and redirect the wind around my structures. I am looking into how the size and height of these obstructions would dictate the distance that a structure could be set back and still have adequate protection from the winds.

Vegetation Protection

For century's farmers and landowners have used landscape, predominantly trees, as barriers and windbreaks. These barriers are used to redirect and reduce wind. The reduction in wind speed behind the windbreak modifies the environmental conditions and helps against wind erosion. Windbreaks reduce wind speeds up to 30 times their height downwind.[11] Using trees and shrubs gives you the best areas of shelter against wind but with the strength of winds from tornadoes there is the potential of adding debris thrown with such force they are commonly referred to as missiles. When a tornado comes through it breaks off branches and there for, rather than providing a barrier, the branches are added to the debris cloud of the tornado. The pros and cons must be weighed before adding trees into your design. If using these trees as windbreaks, a guiding criteria will be the distance between the trees and the house. Using trees as windbreak they must be placed far enough away where they will divert the wind around the house but not too close were tress can cause damage to the house by falling on the structure. The ideal distance is around 150 to 200 feet away from the house and make sure the windbreak is dense enough that it can divert the wind, slow the wind down and that it catches a lot of its own debris before it reaches open areas.

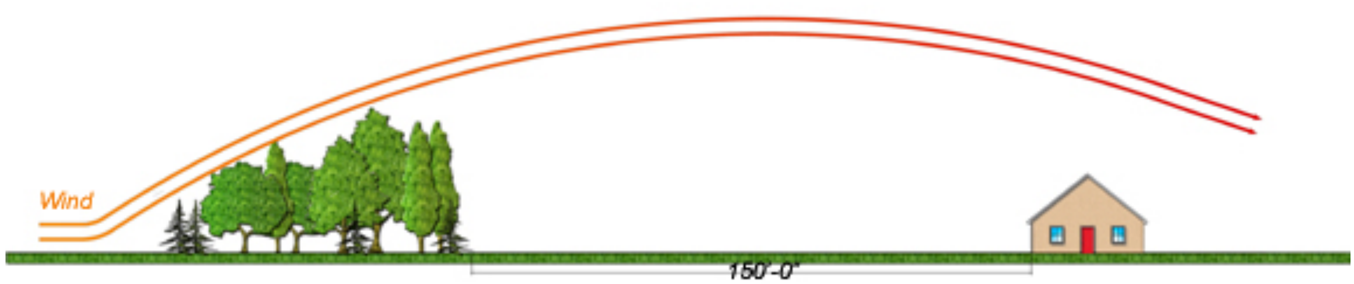

Figure 12: Wind Diagram Vegetation
Made by Author

[11] (Kuhns)

Wind Tunnel Testing

During the research process I wanted to get a more in-depth look at wind testing. I new what direction most of the tornadoes are coming from and felt that knowing the direction I could orient landscape and the house to be better protected against the tornado. I built a wind tunnel where I could test roof angles, different sizes of hills and walls and look into the distances that the house could be placed away from these sources of protection.

Figure 13: Wind Tunnel
Made by Author

6-Foot Wall

This research criteria was to test a 6 foot wall in there position: adjacent to a house that is 10 feet and 20 feet away from the wall. A barrier wall next to the house serves as debris protection against the exterior walls essentially acting as a thick exterior wall. It does little to deflect the wind. When the wall is placed at 10 feet and 20 feet away from the house the wind is deflected over the wall and over the roof structure. Some turbulence is occurring when the wind hits the wall and is forced over the barrier.

The wall structure must be able to withstand full wind pressure to prevent from blowing over and be able to withstand the missiles caused by a tornado. A well-constructed wall near a house will minimize the damaging affects of a tornado on a house by deflecting the wind and damaging debris around and over the house.   To see the maximum protection from a 6 foot wall the spacing of the wall away from the structure should be less than 20 feet.

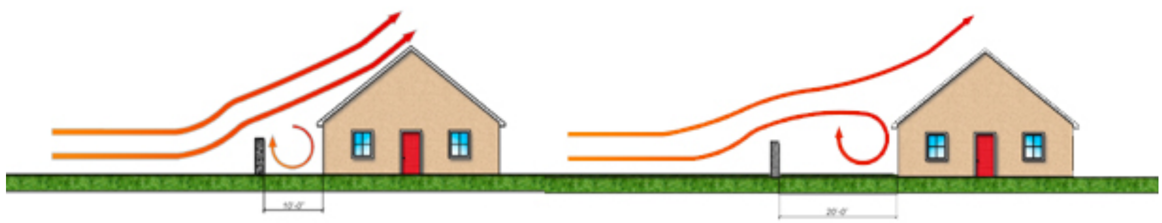

Figure 14: Wind Diagram 6 Foot Wall
Made by Author

Berm Wall

The berm wall has some of the similarities to the barrier wall but it is built with more mass, which offers greater resistance to wind. Directing the wind around the structure will minimize turbulence and pressure on the windward side. When placing the berm wall adjacent to the house the berm deflects wind over the house and offers good protection for the house against flying debris. When a bermed wall is set back from the house the performance is similar to the barrier wall; a wind vortex can form between the wall and house. With separation between the house and berm wall of 20 to 40 feet some wind is still deflected over the house but with less affect. When the bermed wall is placed 40 to 60 feet away from the house, the house will have stronger wind loads placed on the structure but even at 60 feet the berm is still absorbing the flying debris and some of the wind speed so these forces are not as great as an unprotected house. To see the most protection of a bermed wall the spacing of the wall from the house should be less then 20 feet.

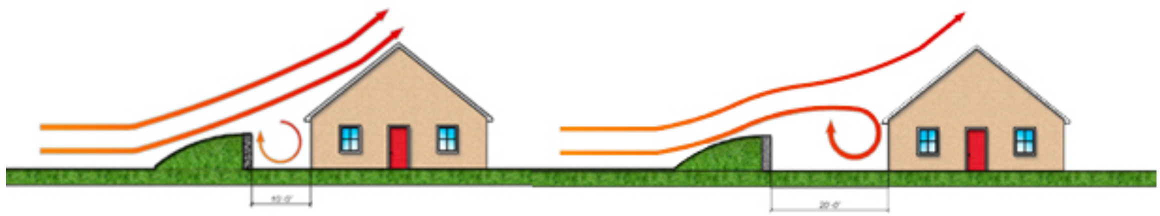

Figure 15: Wind Diagram Berm Wall at 10 and 20 Feet
Made by Author

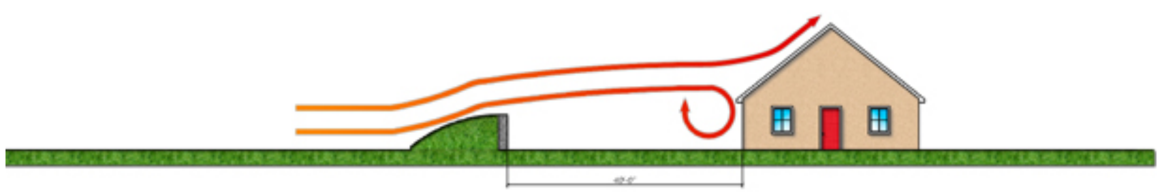

Figure 16: Wind Diagram Berm Wall at 40 Feet
Made by Author

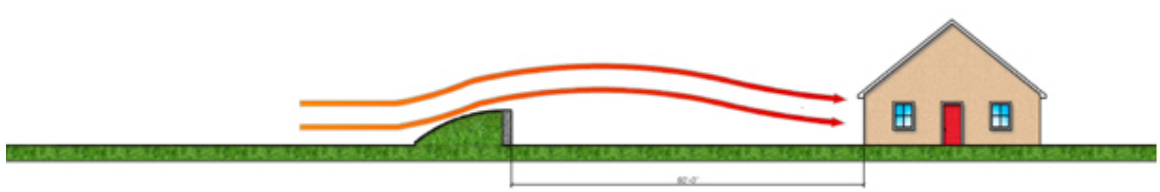

Figure 17: Wind Diagram Berm Wall at 60 Feet
Made by Author

10-Foot Hill

When placing a hill near a house your desired effects are to get the hill to absorb the destructive flying debris before it hits the house. Also looking into diverting the wind around the structure and by slowing the wind down before it hits the house. When the hill is next to the house it as a similar effect of a berm up against the house in deflecting wind over the structure. When the house is 30 feet away from the hill the wind is still deflected over the structure but a small amount of wind is hitting the walls. When the hill is 50 feet away from the structure it has stopped deflecting the wind over the structure and now onto the walls but it will still be slowing the wind down and absorbing some of the debris. When using a 10-foot hill to deflect the wind over your structure the hill should be place 30 feet away or closer.

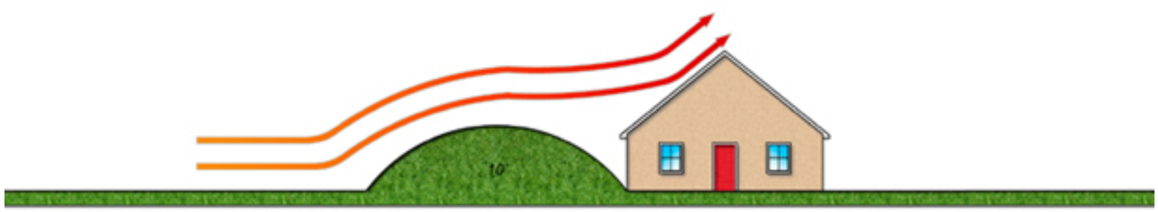

Figure 18: Wind Diagram 10 Foot Hill
Made by Author

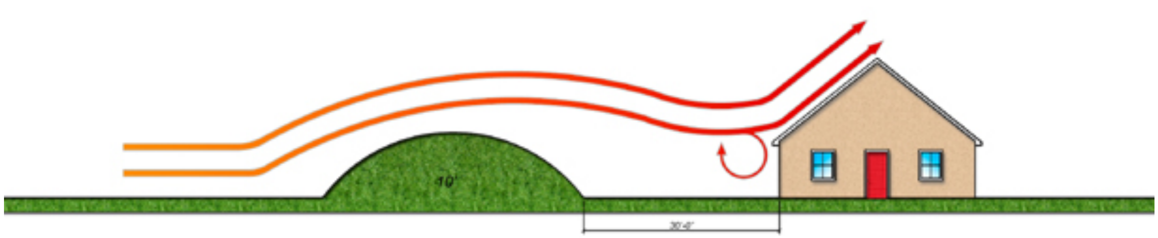

Figure 19: Wind Diagram 10 Foot hill at 30 Feet
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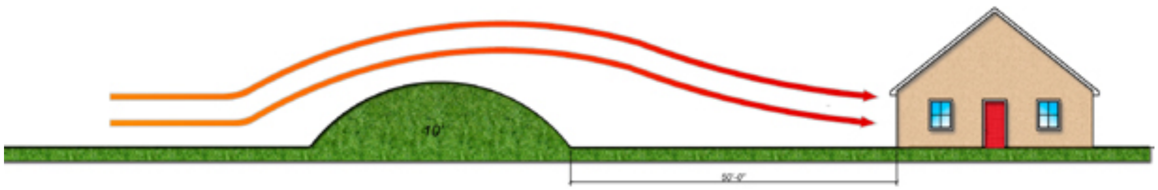

Figure 20: Wind Diagram 10 Foot Hill at 50 Feet
Made by Author

15-Foot Hill

This next test was to see the effects of a taller hill at the same distances from the house as the 10-foot hill. Like the 10-foot hill test, the 15-foot hill was placed 0 feet, 30 feet and 50 feet away from the house. When the house is at 30 feet or closer to the hill the wind is deflected completely over the house and not deflecting off the roof structure. With the house at 50 feet away the wind is deflected onto the roof structure and over the house. The use of a taller hill allows the house to be placed at 50 feet and still have substantial protection from a tornado.

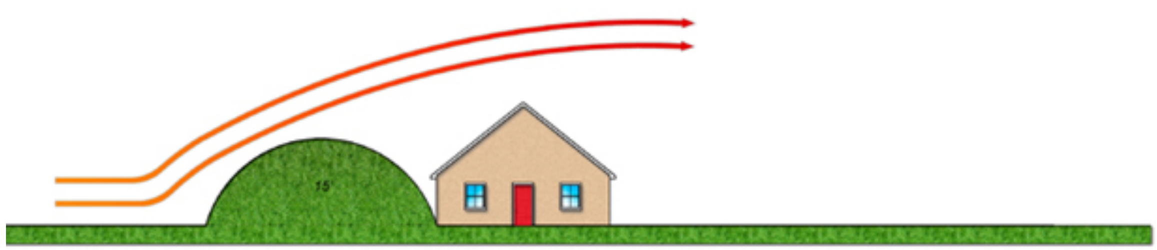

Figure 21: Wind Diagram 15 Foot Hill
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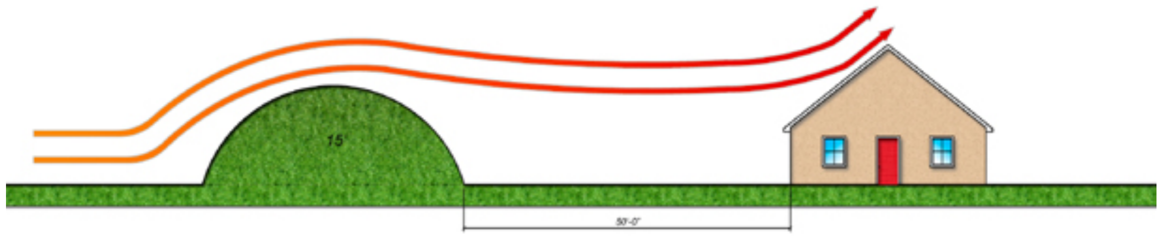

Figure 22: Wind Diagram 15 Foot Hill at 50 Feet Away
Made by Author

Multiple hills

This test was to see if having two hills next to each other would have more of an affect on the wind and the debris over just one hill. This test is looking at an 8 foot hill and a 10 foot hill next to each other with a house at 0 feet, 30 feet and 50 feet away from the hills. When the wind from a tornado reaches the two hills this provides twice the area to direct the wind up and over the house and more of an area to slow the wind down and absorb some of the debris. Directing the wind over the roof structure from 30 feet and less all wind is directed over the structure. When the house is set at 50 feet wind is directed over the structure but some wind is hitting the walls. What I have learned from this test is that having two hills gives you more of a surface area to slow the wind down and absorb debris and you can gain a few more feet in spacing between the hills and house but the separation between the hills and the house is similar to having one hill.

Figure 23: Wind Diagram Multible Hills
Made by Author

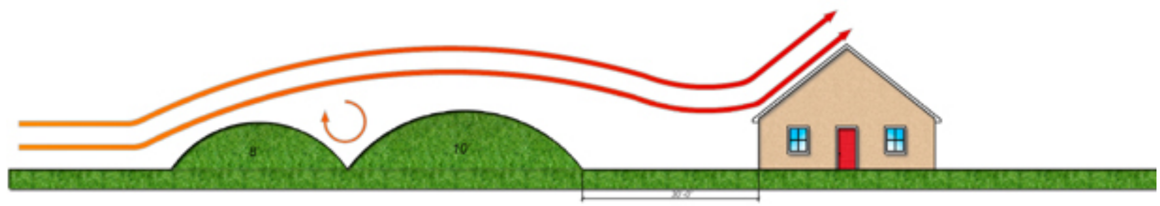

Figure 24: Wind Diagram Multible Hills at 30 Feet Away
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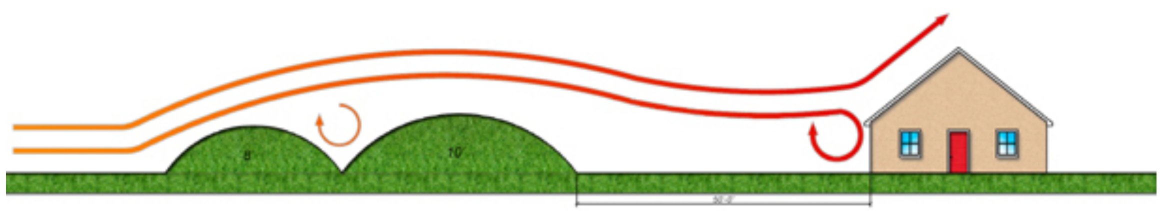

Figure 25: Wind Diagram Multible Hills at 50 Feet Away
Made by Author

2 Hills Two Houses

In this test I organized a 10 foot hill with a house 20 feet behind it and then a 15 foot hill with a house 20 feet behind that hill. Then I reversed it and placed the 15 foot hill up front and the 10 foot hill in the back. With the first scenario the wind is deflected on to the roof structure of the first house and then flows over the first house and completely over the second house. When I placed the 15 foot hill in the front the wind is deflected completely over the first house and onto the top portion of the roof structure of the second house. From these test I have found that the second hill is not needed because the first hill and house is serving as protection to the second house.

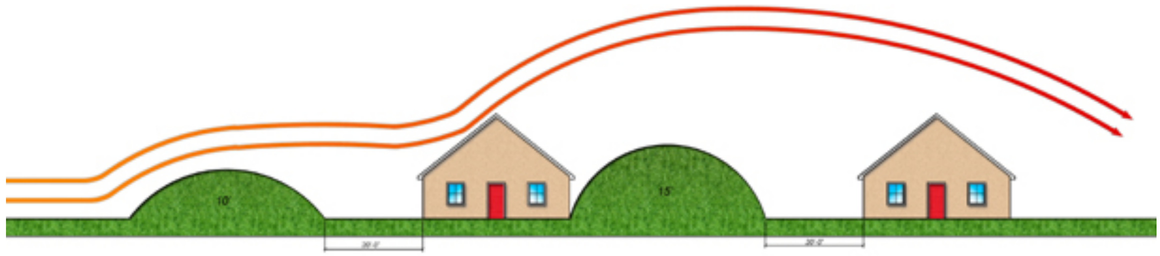

Figure 26: Wind Diagram 2 Hills 2 Houses 1
Made by Author

Figure 27: Wind Diagram 2 Hills 2 Houses 2
Made by Author

10' Hill With 6' Wall and 3' Wall

On these test I placed a 3 foot wall on a 10 foot hill and placed a house at 50 feet away. When I used a 10 foot hill with a 3 foot wall on top, I placed the house 50 feet away because I wanted to compare it to the test I already did of a house and 10 foot hill at a separation of 50 feet. I knew that with out a wall, that at 50 feet the house was not completely protected from the wind and if adding the wall would that improve the protection. With a 3 foot barrier wall on the hill and the house 50 feet away from it, the wind is deflected on to the roof structure and over the house. By adding the wall there is improvement in protection and the ability to move the house farther away from the hill then a hill with out the barrier wall. This 3 foot wall will gain you an extra 20 feet so the house is still protected at 50 feet. When a 6 foot wall is placed onto that same hill the distances double. With the house at 70 feet away the wind is directed completely over the house and at 100 feet away the wind is deflected onto the roof structure and over the house. With the use of a barrier wall on a hill your protection distance has moved from less then 50 feet all the way to 100 feet.

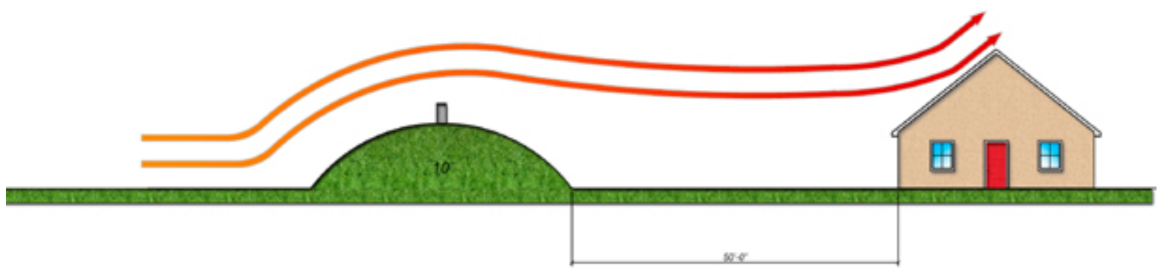

Figure 28: Wind Diagram Hill With 3 Foot Wall at 50 Feet
Made by Author

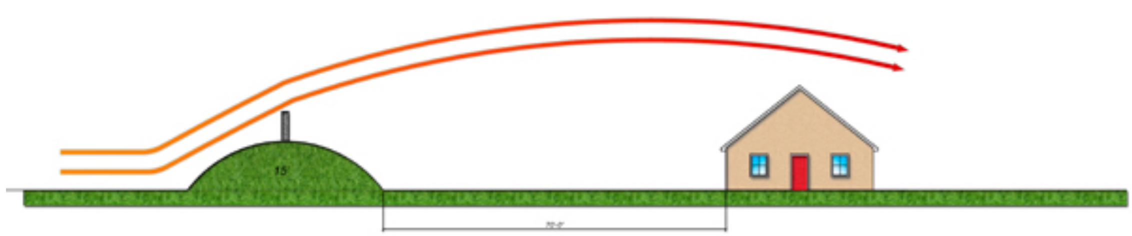

Figure 29: Wind Diagram Hill With 6 Foot Wall at 70 Feet
Made by Author

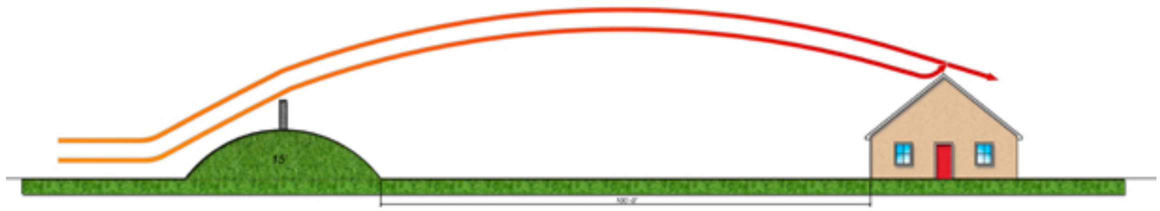

Figure 30: Wind Diagram Hill With 6 Foot Wall at 100 Feet
Made by Author

When looking at these tests one must take into consideration that I am not trying to stop tornadoes. I am looking at ways to absorb the debris that causes the most damage in a tornado and to redirect or slow down the wind so it will have a less affect on the houses I have designed. I can do this by using vegetation, walls, earth and berm structures and positioning them in the right location and orient them in the proper direction to give protection to my house. By using what I have learned from these tests I fell I can lessen the intensity of the tornadoes damage before it hits my tornado resistant house. This will give my house designs a better chance to survive the tornadoes that hit my state every year.

CHAPTER 3

TORNADO PROTECTION

Materials Strength & Testing

When it comes to tornado protection the first thing is to look at easy fixes that will help improve your house. These fixes wont make your house tornado resistant but it is a cheap fix that will help more then not doing anything.

1) Securely anchor storage sheds or other outbuildings, either to permanent foundations or with straps and ground anchors.
2) Plant trees far enough away from homes so that they cannot fall on the homes.
3) Reinforce double entry doors by adding heavy-duty dead bolts, or slide bolts to the top and bottom of the door section that is generally not open. Replace hinge screws in doors and door frames with longer screws.
4) Reinforce garage doors by adding stiffeners across the back of the door and by strengthening the glider wheel tracks.
5) Brace gable end roofs, as they are much more susceptible to wind damage than hip or flat roofs.
6) Protect windows with permanent storm shutters.

Housing Design

No matter the style a home is a place for people to live and work in. These spaces are designed to be functional and comfortable for the occupants to live in for extended periods of time and typically are not designed for extreme weather protection. Homes that meet the requirements of the building code, most often under fulfill this need to protect against these extreme weather conditions and when you live in a state that frequently experiences extreme weather then designing for these issues should be a priority. In Oklahoma the traditionally built house is not expected to withstand extreme weather conditions, they are designed to meet code, which does not address the forces and destruction caused by tornadoes. This thesis addresses these extreme conditions caused by tornadoes. My proposal is to provide three stages of housing protection that will work in conjunction with landforms to provide protection for the occupants against extreme weather (tornadoes) in Oklahoma.

Walls

Walls in the tornado resistant house are very important aspect of the design. The walls must have a solid connection to the roof, the foundation and must be able to with stand the heavy winds from a tornado. With in the high speed winds of a tornado there will be deadly flying debris that can inflict harm on the occupants and damage the structure of the house as it passes through the structure. A solid built rigid structure with good lateral load support and solid connection is the best system for high-speed tornado wind loads. The lateral wind load protection can be met by rigid sheathing (plywood) on the exterior walls, but this structure is still vulnerable to debris penetration. The sips Panel will be an upgrade from your traditional wall, there is still the rigid construction but this system has been approved by FEMA on impact testing. The best wall material is reinforced concrete wall. This material gives you solid connection to your foundation, rigid structure and the best system for debris protection.

Insulated concrete form (ICF) wall is a foam block that stacks and interlocks with each other to make a wall that will be in filled with concrete and r-bar. This is a great material for there is no need for formwork and they are very light and easy to work with. During construction you save time by not having to put up and take down formwork because the wall system is its own formwork. When the concrete sets up you have a solid reinforced concrete wall that is insulated and ready for siding and interior finishes. Being solid reinforced concrete it is one of the best materials to cope with the high winds and debris from tornadoes.

The earth sheltered wall or berm wall is another technique that is well adept for tornadoes. Earth is a great material for protection against high winds and flying debris. Dirt is widely available to mound up around a wall system and also serves as insulation for the building. The down side to this method of construction will be getting light into the building and egress out of the building.

The structurally insulated panel (SIPs) is a structural panel that is made from a wood sheathing like plywood or oriented strand board (OSB) and rigid foam insulation. This product is recognized by several agencies like FEMA for being impact resistant for tornado debris. This product is made by sandwiching rigid foam between two pieces of wood product and this process will make one unit of a SIPs panel that can be used as a wall or roof piece. These panels can be interlocked with each other to make a solid rigid structure that is also impact resistant.

Foundation

In Oklahoma the most common foundation is slab on grade, not many houses are built with deep foundation wall or basements. In my methods I am looking at connections to the concrete slab to protect the house from being blown of the foundation. In your tradition wood wall or a sips panel a sill plate is attached to the foundation to hold the wall to the foundation. This can be with concrete nails or anchor bolts. Code requires anchor bolts at every six feet, code is the minimum and I feel it should be doubled. The strongest method is the concrete wall, the wall and foundation are tied together with rebar that is in both systems. The slab will have rebar protruding from it that that can be tied into the wall system. This makes the wall and foundation one solid unit and there is no fear of being blown off the foundation. These rigid connection are necessary for tornado resistant homes because the foundation connection is one of the places that will most likely fail during a tornado.

Windows and Window Protection

Windows are most likely the first thing in the house to fail and allow the outside conditions to enter the house and cause damage to the house and injure the occupants. We need windows to allow light into the structure but this is the weakest point for debris entry and steps need to be taken to protect the house.

Storm shutters are widely used in areas that are subject to frequent hurricanes; these areas are subject to flying debris just like the Midwest. Two shutters that I could see being used in Oklahoma are the accordion and roll down shutters. These shutters will not prevent your windows from breaking but will prevent flying debris the opening and compromising the structure of your house. These two shutters are permanently attached to the house and are manually cranked out to protect the window or in the case of the roll down it can be motorized. These systems come with a price, for your average size window it will cost you 200 dollars for the accordion shutter, 400 dollars for the roll down shutter and 700 dollars for a motorized roll down shutter. [12] The downside of these systems are going out and cranking them down tornadoes are not like hurricanes there is not a several day notice that your house will be hit, in tornado alley you are looking at a matter of minutes. This limited amount a time makes it to dangerous to go out and put your shutters in position, unless you have the motorized shutters set up were you press a button and they all come down at the same time. This could work but know you need to look at the price of each shutter and see if there is an alternative material.

Two more alternative window protection systems are hurricane fabric and C-foam panels (carbon foam). The C-foam panel is a new material that is used in several different applications, but in my application is for debris impact. This material has successfully been tested to stop a 2x4 wood stud at 100 mph.[13] This is a new material so there are not many manufactures and I cannot find a price so this makes me think it will be expensive.

The most common alternative is hurricane fabric; this is used in place of shutters and plywood to protect openings. Hurricane fabric is a geo-synthetic textile designed to stop debris and reduce wind; this fabric can reduce a 100 mph wind to 3 mph. [14] This material is made by several manufactures and ranges from 100 dollars up to 200 dollars for your average 3’x5’ window. This material is made for hurricanes in the since it is put

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[12] (Rolling Shutter)
[13] (C-foam)
[14] (Astro Guard 2011)

up before the storm reaches landfall. This cannot be done for tornadoes because the limited prediction time, so for this material to be successful in Oklahoma a way must be derived to deploy it quickly.

Instead of trying to protect the window the alternative to this is a window that protects itself. These are impact resistant windows, PET laminated glass or glass clad polycarbonate. These are laminated glass windows like your car windshield. These windows can take impacts with out shattering or compromising the opening. These windows are great for protection there is no need to have shutters or hurricane fabric to protect the opening, but they are three to four times more expensive then a typical window.

We know that window openings of a house are the weakest point in a tornado resistant house and steps need to be taken to protect these openings. All windows should be protected but especially the windows on high risk sides like the Southwest and West sides of the house. The best protection can be found by using impact resistant glass or storm shutters. With the use of these products protecting windows and openings a safer house can be built for the users.

Roof and Roof Connections

Strong roof to wall connections are an important part of tornado design in preventing the roof from lifting off of the walls. This is another weak point in the design of houses in tornado prone areas. Hold down clips will provide a rigid connection into the wood or concrete wall that will prevent the roof from flying off. The use of these clips will make a solid structure that will tie the roof into the wall and give the best protection against tornadoes.

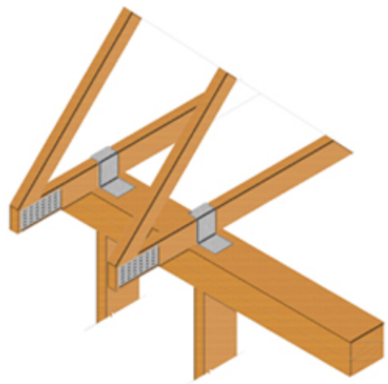

Figure 31: Rafter Clips
Made by Author

The roof angle is an important part of the house because of the wind shear that will be placed upon it. When wind meets a flat roof it will produce the most wind shear because it is not designed for wind to pass over it. Wind will travel over the surface of a flat roof or low angle roof faster and can cause lift on the roof surface like an airplane wing. High angle roofs allow the wind to travel over the roof with out providing lift on the structure.[15] Forty-five degree-angled roof provides the least amount of wind shear. There is a possibility of a flat green roof that can be used in conjunction with berms, the berms will direct the air over the roof and the mass of soil from the green roof will help in the prevention of lift. This can be looked into if one is looking for more of a green aspect to their design.

[15] (Clemens)

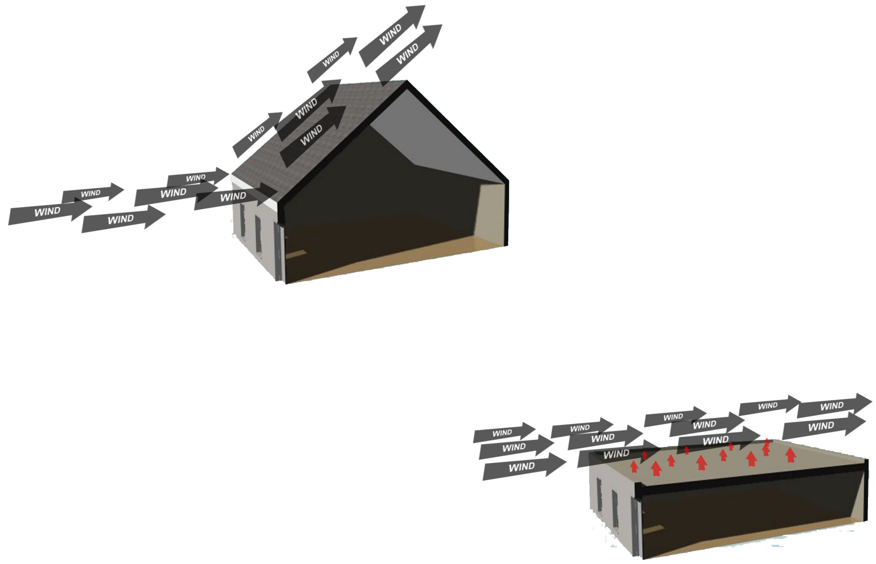

Figure 32: Roof Diagram
Made by Author

Roof irregularities are good for reducing wind loads on the roof structure. If the roof has irregularities in it that are not low sloping, then this makes the roof less likely to gain lift. In the tornado designed house we want wind to easily flow over the house, but we want irregularities in the roof to break up the wind so wind speeds can not increase and cause lift on the structure as it passes over.

Another aspect in the roof construction will be venting on the leeward side of the house. This venting will reduce problems that are commonly associated with the pressure drop that occurs during a tornado.

Debris penetration is the main problem from a tornado, so every portion of the building must take this into consideration especially the roof. If the wind is flowing over the roof then that means the debris is flowing over it also. This means we need to protect against the debris from coming through the roof into the house. The problem to this is to find a product that is rigid and easily attached to the rafters and that will keep the debris out. This product must serve this purpose but be light enough not to but extra strain on the structure but be able to be held down so it can be blown away. At this time for a sloped roof I think the sips panel is the best, this product is recognized by FEMA for debris protection and it is easily attached to the roof rafters to make one solid rigid system or can be used without rafters because of its structural stability.

Berms

Berming is a good way to add protection to a house, the berming of earth around a house can serve several functions. Bermed walls make a barrier that helps direct the high winds around and over the building. Earth makes some of the best impact resistant material; gun ranges use earth embankments to stop bullets so they should also be good at absorbing the impact of debris from tornadoes. The added benefit of using earth berms is that soil makes a good insulation material. This added insulation would add to the interior comfort of the house and help with cooling cost of a hot Oklahoma summer. Geothermal piping can be laid in the berm during construction, which will save on the cost of traditional drilling that is used in the installation process. These berms can be placed on any side of the house were protection is needed but consideration needs to be taken on allowing light into the building as well.

Stage 1 Housing

Figure 33: Stage 1 Checklist
Made by Author

The Stage 1 house will be your most basic design for tornado protection. When looking into the Stage 1 design, I feel these design elements should be added into the building code for all new construction. In California code requires structures to be designed for seismic activities, so why can't Oklahoma require structures be designed for tornadoes. Also some of these elements can be retro fits for existing structure, for example rafter clips, impact resistant windows, storm shutters.

The first aspect of the stage one design will be the placement of the house with in the landscape, to give it the most protection. This house should be a central design were the occupants most used areas are in the middle and will have the least used area along the exterior walls were there is a possibility of debris penetration. The house will be designed with a safe room centrally located in the house to be used during a tornado encounter. The wall material will be wood framed because of most common used material with plywood sheathing on all exterior walls for lateral support (code requires lateral support on corners only) but extra sheathing will not provide impact resistance. This construction will meet the wall to foundation connections and the wall to roof connections that were described previously, this will give the structure the strongest and most rigid construction for wind protection. The openings of the house on the West and Southwest side will need at least one of the two recommended items, which were impact resistant window or storm shutters. The roof will be set at a steep angle up to 45-degrees to protect against debris and allow airflow over the structure. When designing the house try to incorporate as many irregularities into the roof to help break up the wind over the roof to prevent up lift.

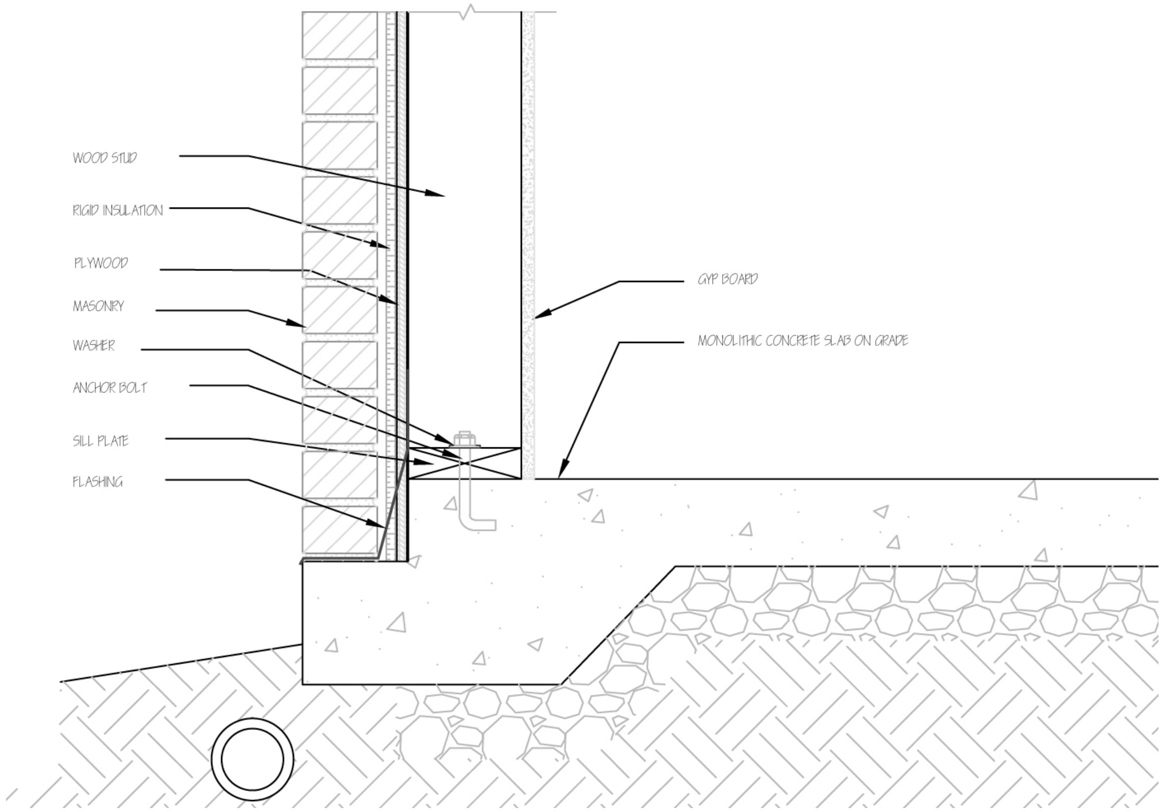

Figure 34: Stage 1 Foundation
Made by Author

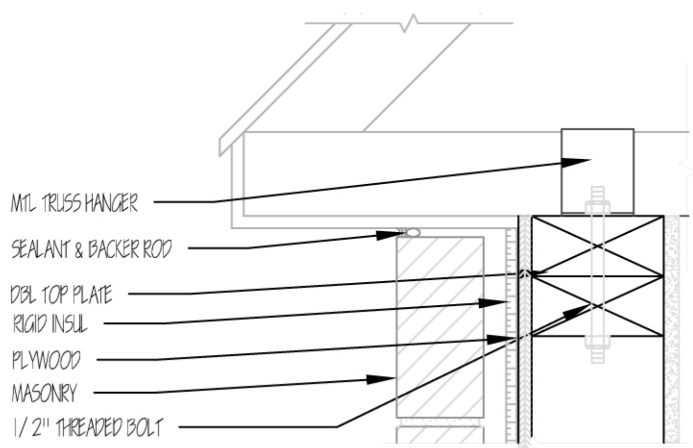

Figure 35: Stage 1 Roof
Made by Author

Stage 2 Housing

Figure 36: Stage 2 Checklist
Made by Author

The Stage 2 house will also be incorporated into the landscape to give the most protection to the house. The biggest part of the design will be the use of berms in the design. Berms will be added around the house in the areas of most needed protection. The house can be a central design but not needed because the house is using earth berms and wall materials for protection. The wall material will be some kind of reinforced concrete; this can be insulated concrete forms or cast in place concrete or made from SIPs panels. This will have the same roof system of the Stage 1 house, steep angle sip roof to allow the most protection and airflow movement. The stage 2 house will follow the rule of the stage 1 house on the protection of openings.

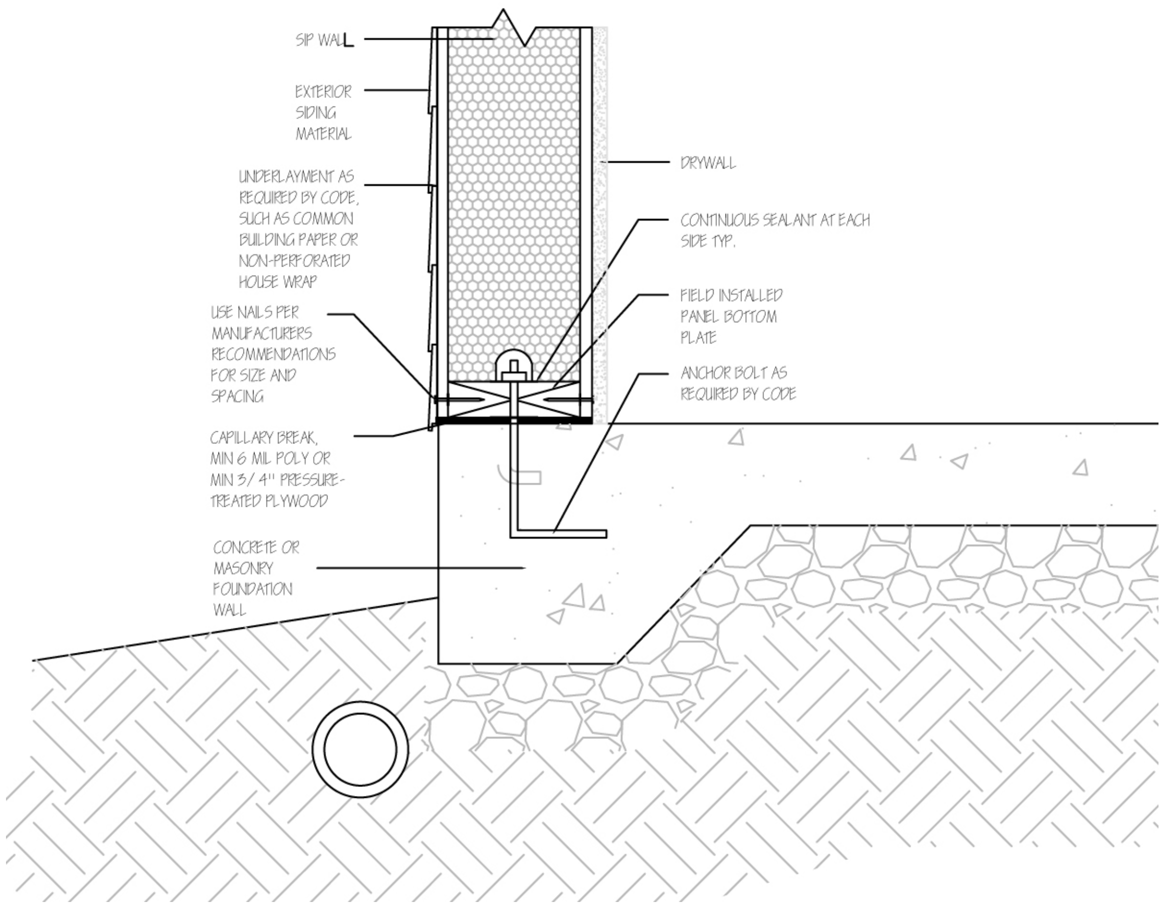

Figure 37: Stage 2 Foundation
Made by Author

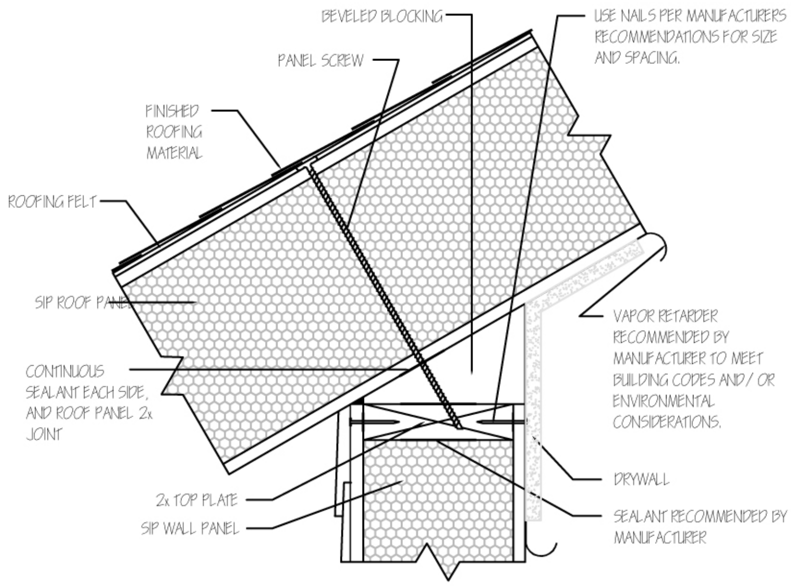

Figure 38: Stage 2 Roof
Made by Author

The stage 2 house that I have designed is a 3 bedroom 2400 square foot single story house. The house has a central design plan that is oriented on a Southwest axis with the back of the house facing toward the Southwest. The house is bermed on three sides to give protection against the high-speed wind and air born debris caused by the tornado. Enclosed within the berming around the house is an outdoor protected courtyard that can be used as a back yard. The walls and roof are built out of SIPs panels for their strength and impact resistance. The opening of this house have impact resistant glass and roll up storm shutters to protect this weak point from flying debris.

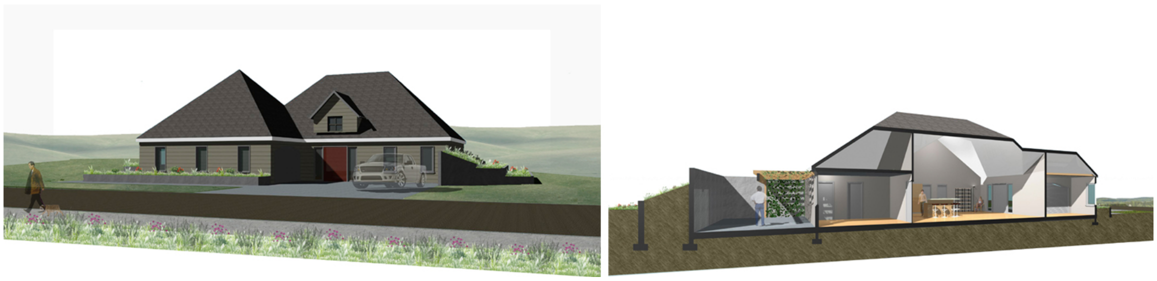

Figure 39: Stage 2 Elevation & Section
Made by Author

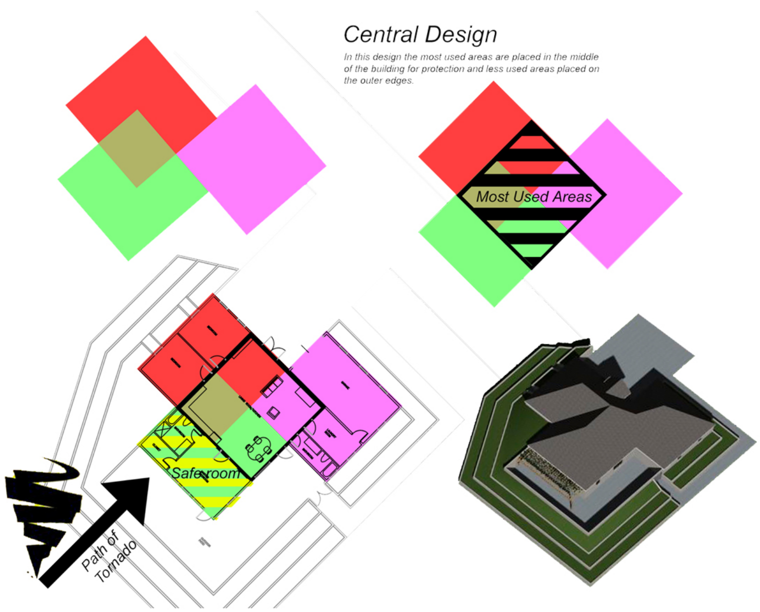

Figure 40: Centralized Diagram
Made by Author

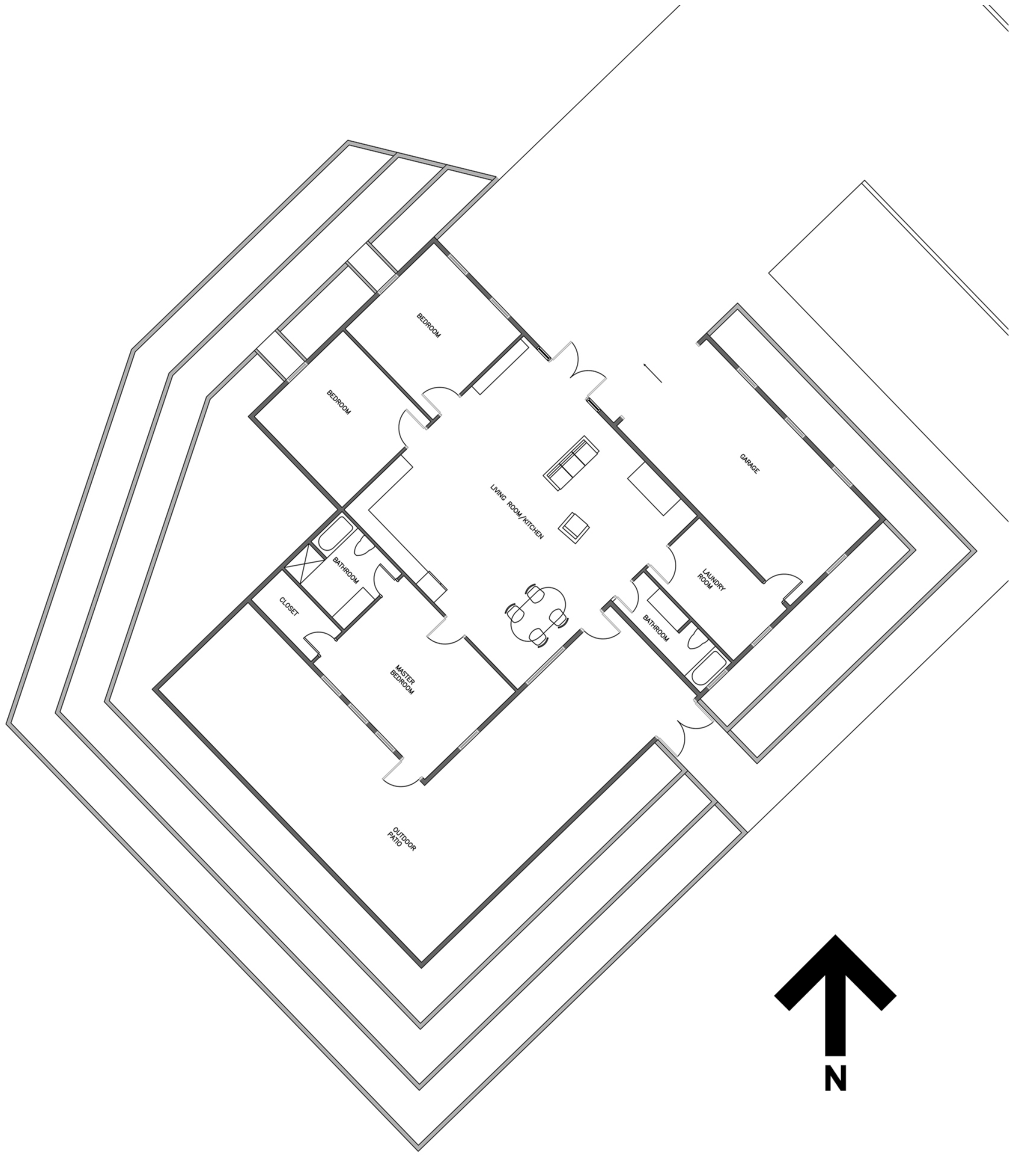

Figure 41: Stage 2 Floor Plan
Made by Author

Stage 3 Housing

Figure 42: Stage 3 Checklist
Made by Author

The Stage 3 house will be the most protected house against tornadoes. This house will be completely built into the landscape to give it the maximum protection against tornadoes. This will be a reinforced concrete structure that will be built into a hillside, an in ground house or a house that is completely bermed on all sides. Special consideration will be made on the placements of openings to allow light in but still be protected against danger. The opening will be of impact resistant glass and have a shutter system incorporated into the design. The house will be incorporated into the landscape so the roof system will be of earth, so this needs to be taken into consideration for the construction and strength of the materials.

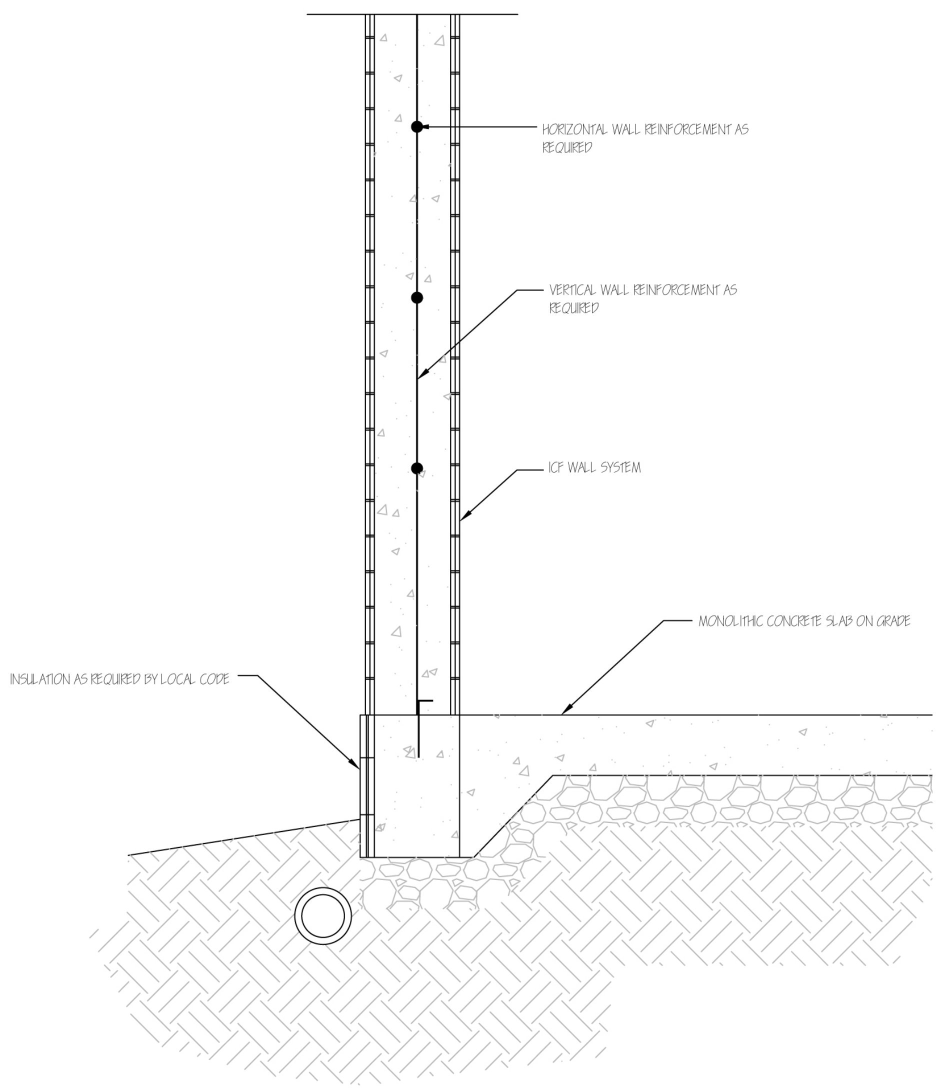

Figure 43: Stage 3 Concrete Foundation
Made by Author

I have designed a 3 bedroom stage 3 house that is 3000 square feet and is built within a hill. This is not a completely underground or covered house, this house is cut into the hill were the majority of the house in underground but the northern portion is exposed. A green roof is placed on the house were the roof structure is not covered by the hill and this is to tie all parts of the house together with the hill. This is a reinforced concrete structure that is oriented with the back of the house toward the Southwest. The orientation of the house will allow maximum protection because we know that 76% of tornadoes come from the Southwest and the West and on these high risk sides the house is covered and protected by earth.

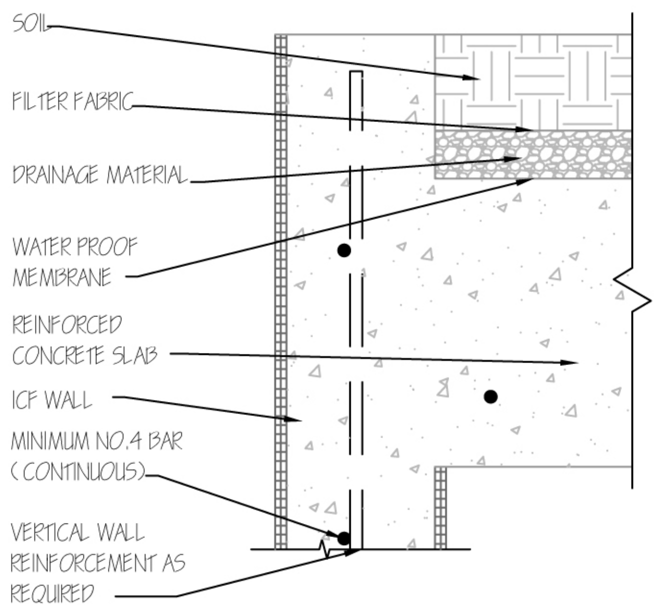

Figure 44: Stage 3 Roof
Made by Author

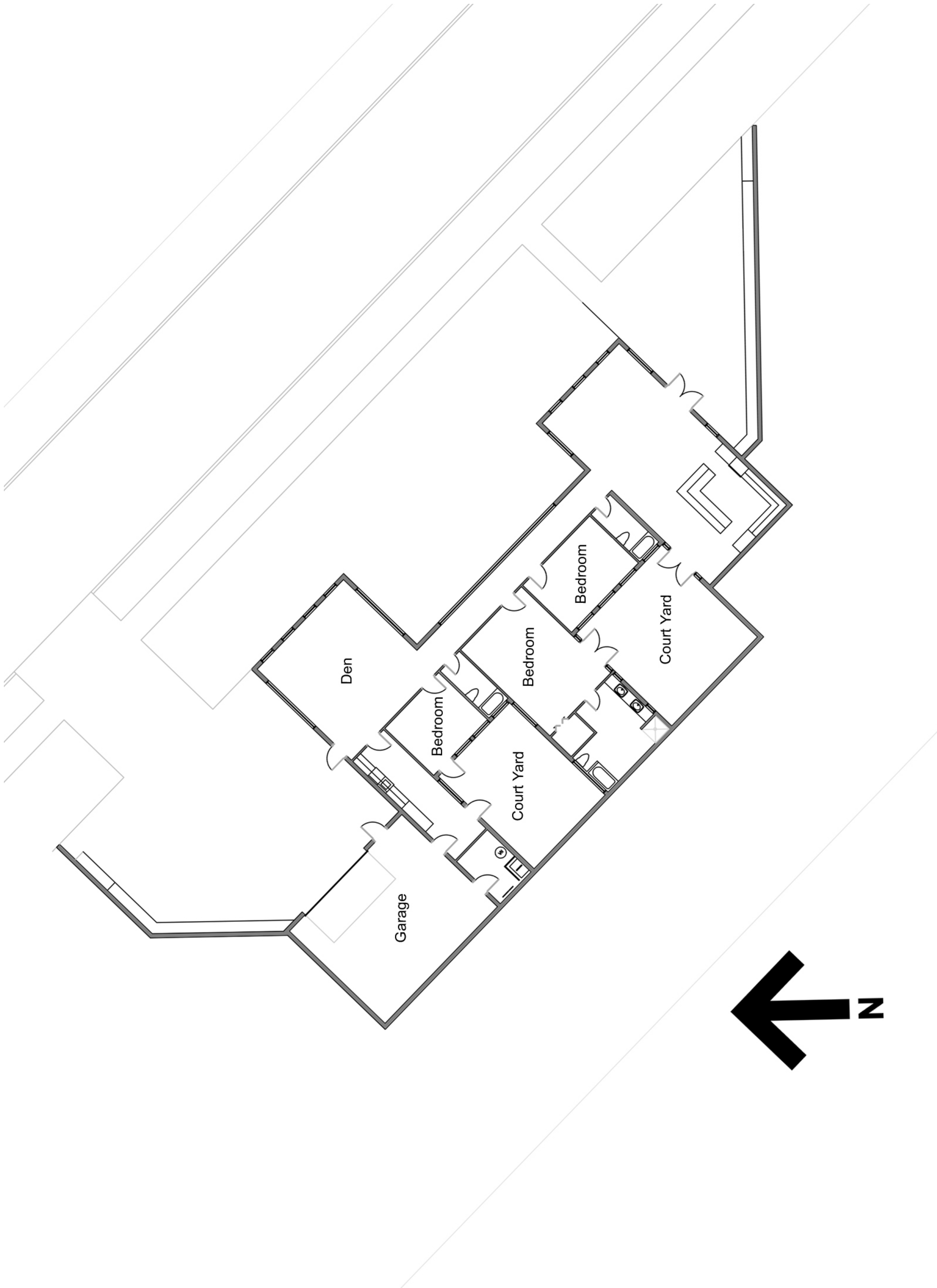

Figure 45: Stage 3 Floor Plan
Made by Author

The structure of this house is entirely built from reinforced concrete. Reinforced concrete is the best when it comes to building for tornadoes, it has the strength to with stand the high wind loads and is a great material for its impact resistance against flying debris. These are the reasons that the roof, walls and slab are made from concrete, and the ability to tie them all together with the reinforcing bars to make a solid rigid box that can with stand the damages that will come from a tornado.

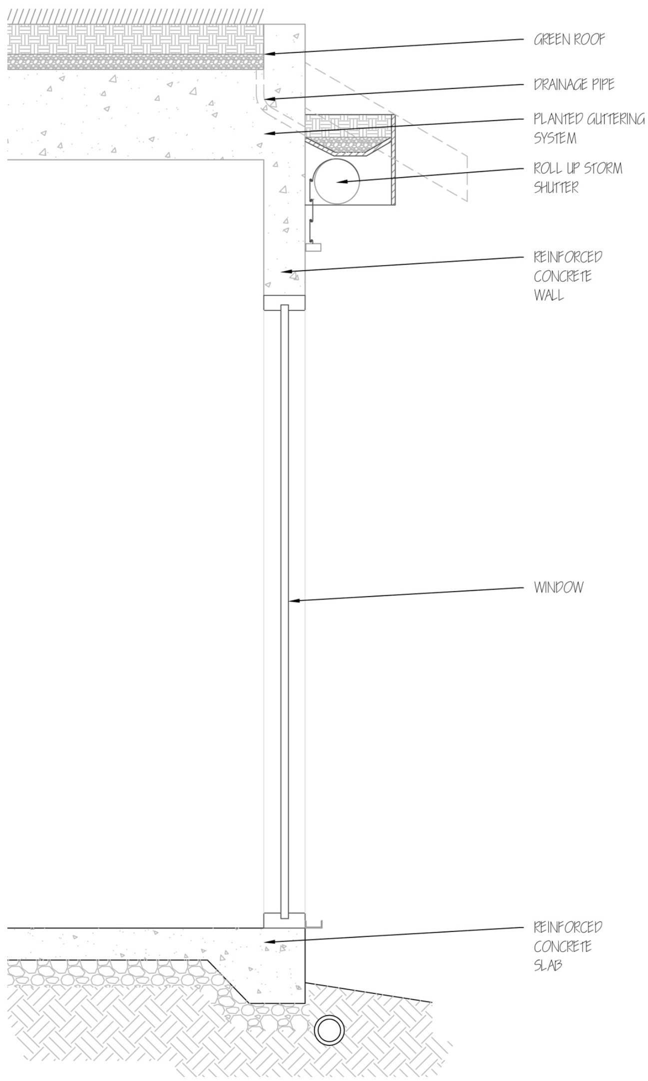

Figure 46: Stage 3 Wall Section
Made by Author

The house designed for protection in the hill and achieves that but also made to be friendly to live in. This house was made very linear and open to the north to allow as much light in as possible and designed around two court yards that were cut out of the hill. These court yards provide a protected out door space for the users and an access point to get southern light into the building. The northern side of my house is left open with a large number of windows to get light into the building and to make it feel open and not like a cave. To make the house feel open and not like you are surrounded by earth and living in a cave was a big selling point, I want people to feel the same in my house as they would in a traditional stick framed above ground house and I am doing this through the use of all the windows and outdoor spaces. Protection must be considered into the design to protect these openings and court yards from the affects of tornadoes.

Figure 47: 3D Section Courtyard 1
Made by Author

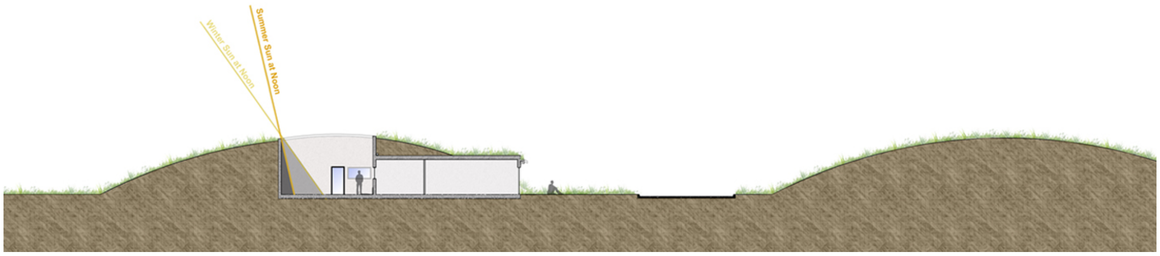

Figure 48: Section Courtyard 1
Made by Author

Figure 49: 3D Section Courtyard 2
Made by Author

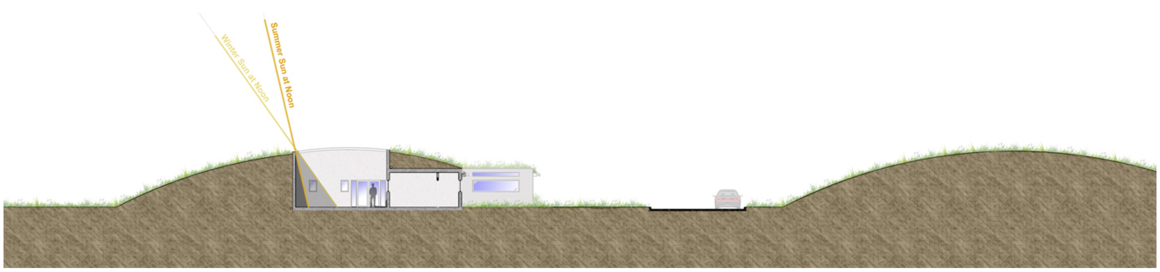

Figure 50: Section Courtyard 2
Made by Author

The windows must be protected because they are the weak points in this design. The courtyards must be protected also because they have several windows in them to allow light into the building. The protection process for the court yards will be dual purpose, there will be a mechanical louver system, the louvers can be closed completely during a storm to allow the wind and debris to flow over it and can be used as an adjustable shading device during the long hot summer days in Oklahoma. A roll up mechanically controlled shutter will protect the windows in case of a tornado. These shutters will go up and down by a push of a button, when the sirens are heard the occupant hits a button and all the shutters will go down to protect the windows. If power is lost the house is equipped with a generator to run all the essential items that the house will need during the storm. These essential items are the louvers in the court yard, the shutters, a information device radio or television and any emergency lighting.

Figure 51: Courtyard 2
Made by Author

The Stage 3 house is the best way to protect your self from tornadoes. This house takes every thing that was learned in my research about tornadoes, materiality, orientation, landscape and vegetation protection and uses all this information to make a new and improved house for Oklahoma that will protect against tornadoes.

Figure 52: Perspective 1
Made by Author

Conclusion

Living in Oklahoma and in the middle of tornado alley we know we are at a high risk of being hit by a tornado and steps need to be made in the building code and the quality of building to help prevent the damages that have accord in the past. We are making huge strides in learning about these storms and how to predict tornadoes to allow more of a warning time but we also need to look at the structures that protect us. We can predict tornadoes all day and lengthen the warning times but this will have no affect in less we can protect the people and we can only do this by strengthening the structures that they hide in from the tornado.

Figure 53: Perspective 2
Made by Author

Figure 54: Perspective 3
Made by Author

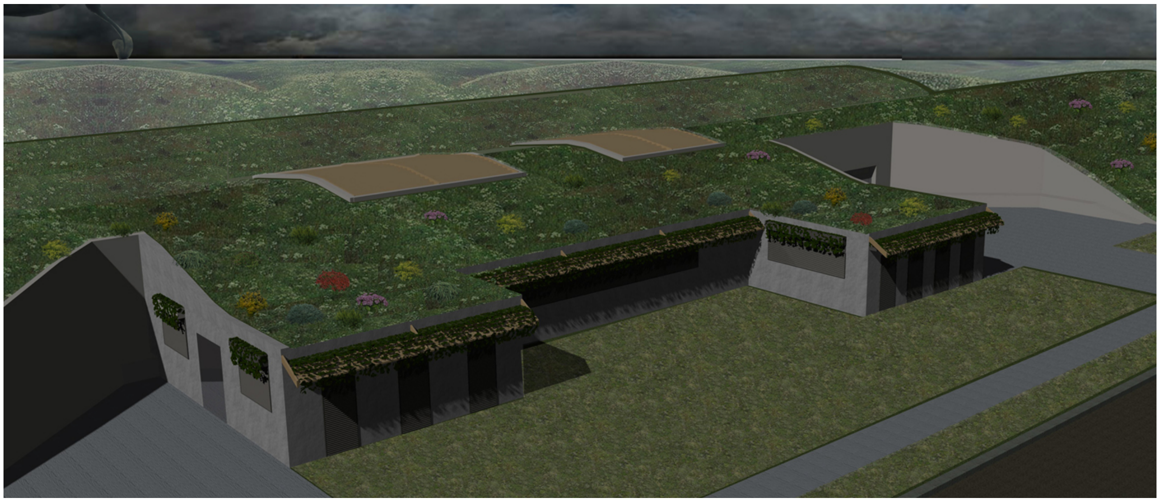

Figure 55: Perspective 4
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Figure 56: Perspective 5
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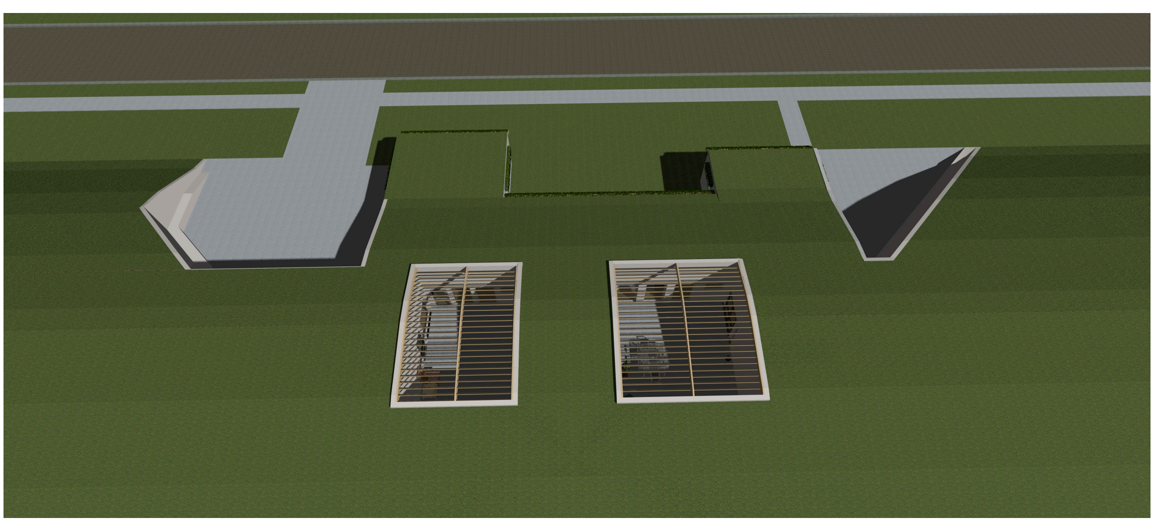

Figure 57: Perspective 6
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Figure 58: Den
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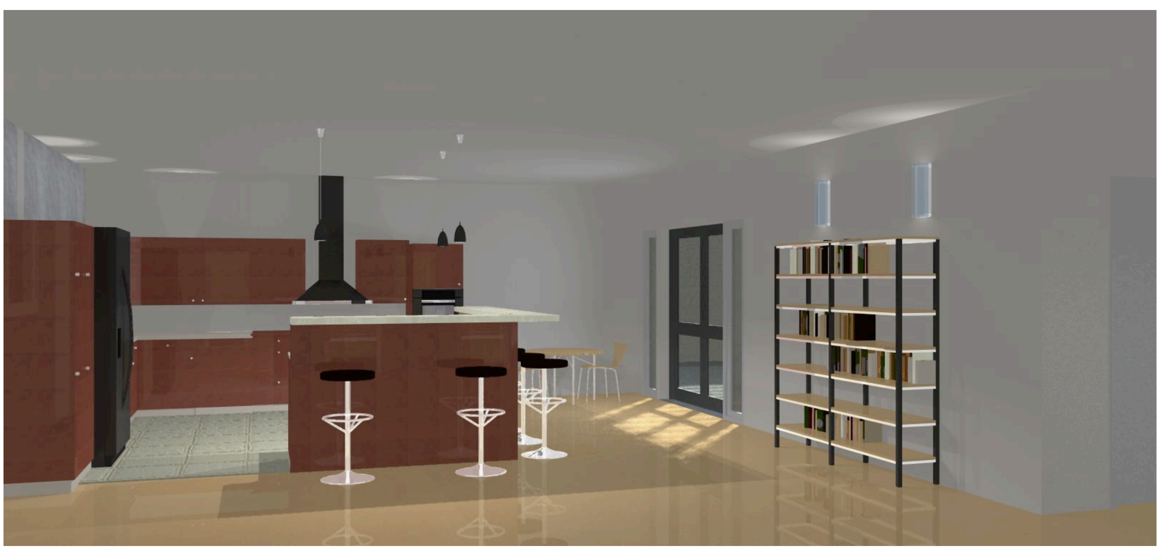

Figure 59: Kitchen
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